

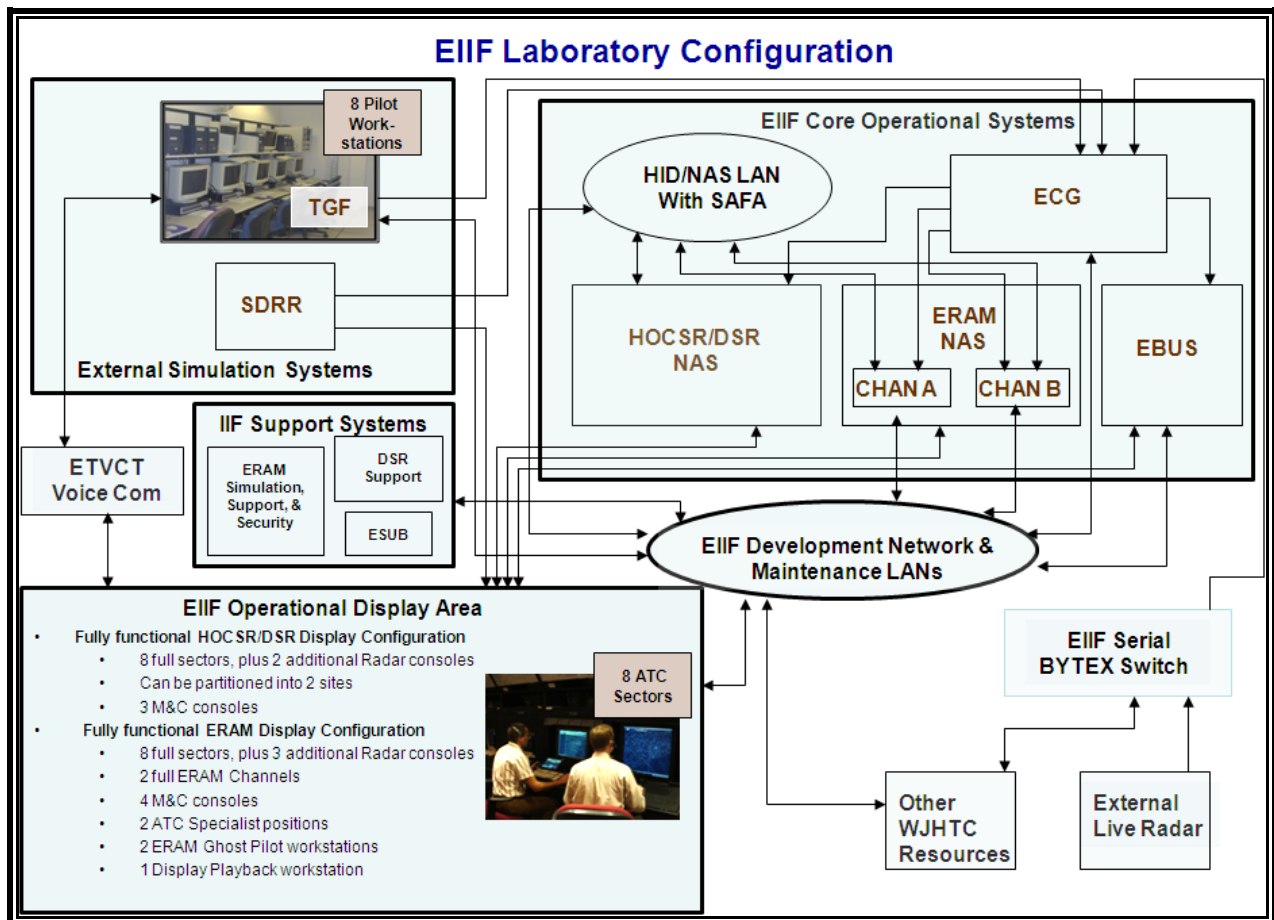
En Route Fuel Optimization Study using the William J Hughes Technical Center's En Route Integration and Interoperability Facility

Abstract

Examining new technology in operational real time systems such as those found in the FAA's National Airspace System (NAS) is a tricky business. In most cases these systems are tightly closed with no easy way of interfacing any kind of new functionality. Many researchers opt for medium or low fidelity emulation to conduct research because of the constraints associated with these types of systems. Addressing this issue is a common occurrence in the FAA's Integration and Interoperability Facilities (IIF).

William J Hughes Technical Center En Route IIF

The En Route IIF (EIIF) is located at the William J Hughes Technical Center (WJHTC) in Atlantic City, NJ. It is a high fidelity laboratory that contains all the systems of an Air Route Traffic Control Center (ARTCC). These facilities are used to control all air traffic that has reached flight level or is transitioning to and from Terminal air space (i.e. landing/ taking off). There are twenty of these facilities across the United States. The systems that comprise the EIIF are open to hardware and software modifications for the purposes of research and development. Maintaining an environment such as this can be difficult. There is always an element of balance that must be maintained between fidelity and flexibility in the laboratory environment. In order to establish the EIIF systems as high fidelity, all of the software and hardware must be maintained and up-leveled in synchronization with the rest of the operational ARTCC systems across the country. An array of simulation systems have also been developed and interfaced to the EIIF operational system for the purposes of conducting simulations using the highest fidelity. One system in particular is the Target Generation Facility (TGF). The TGF provides a mechanism to present simulated aircraft, via radar targets, with pilot communications to air traffic controllers within the EIIF air traffic control room. This is very useful when conducting Human in the Loop (HITL) studies. A high level functional diagram of the EIIF is depicted below. Note that there a development network within the facility that bridges the many simulation mechanisms to the operational environment.



The following case study describes an activity that was conducted within the EIIF.

Case Study: En Route Fuel Optimization Tool

Introduction

In 2009, the WJHTC Lab Services Division Concepts and Systems Integration (CSI) branch was approached by the Office of Environment and Energy (AEE) to assist in conducting a study involving a previously developed tool (“optimization-based automated tactical controller“) for En Route air traffic conflict resolution that would take fuel consumption into account. The study was funded by AEE and performed by the Georgia Institute of Technology under the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence, Project #5*. The tool had been previously tested via fast time simulations at Georgia Tech using historical data from the Cleveland, OH ARTCC. During the fast time simulations, the tool’s flight plan recommendations showed significant improvement over the actual flown routes in terms of fuel burn. Aside from assessing performance of the tool in this environment, some additional issues that AEE and Georgia Tech were interested in examining were operational suitability for a tool of this nature as well as development of operational techniques for its use.

The EIIF organization was selected to work with AEE and Georgia Tech on their En Route Fuel Optimization (ERFO) study because it offered a high fidelity environment that could be modified to integrate a prototype that included the tool developed by Georgia Tech.

A team from Georgia Tech developed the concept for the study. – “The problem of fuel optimal multi-level conflict resolution can be stated as follows: Given a set of aircraft at different altitude levels, along with their current position and velocity information, determine the control actions (heading, speed, and altitude changes) such that the aircraft fly conflict-free trajectories while expending minimum fuel.” The team developed a strategic conflict-resolution algorithm to provide air traffic controllers with recommended heading, speed, and altitude changes to avoid conflicts in a fuel-optimal way. While AEE lead the overall goals for the study, Georgia Tech lead the development of the ERFO algorithm, the design of a Human-in-the-Loop (HITL) test program, and the gathering of flight data sample from the Memphis, Tennessee ARTCC.

For this study, the EIIF staff was tasked with the following items: a) Integrate the Georgia Tech developed prototype into the EIIF Air Traffic systems so that it could receive flight and track data and send out flight data updates (amendments). b) Develop a software interface to feed flight data into the ERFO algorithm from the operational system c) Assist Georgia Tech in developing a graphical user interface to display the algorithm output for the controllers. The output would consist of flight data amendment recommendations that would represent complete de-confliction of the flight data set under control of that sector. c) Developed software to format and send flight data amendments back to the operational system. d) Assist Georgia Tech in developing air traffic simulation scenarios for testing of the prototype. e) Provide laboratory support during conduct of any HITL studies.

Lab Configuration

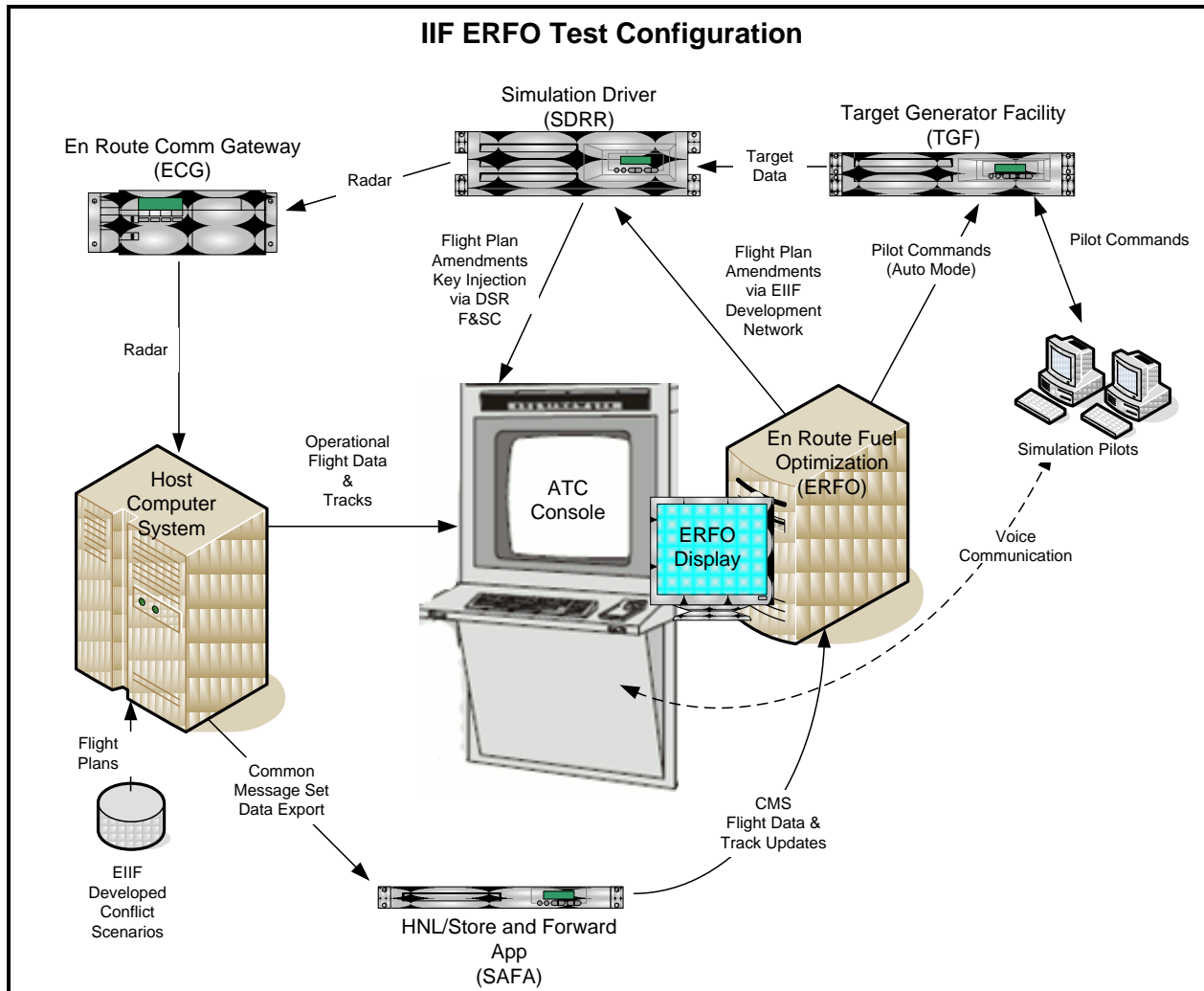
The basic configuration for the study utilized the current FAA En Route Systems – Host Computer System (HCS), Display System Replacement (DSR), User Request Evaluation Tool (URET), En Route Communication Gateway (ECG) and Host Interface Device (HID)/NAS Local Area Network (HNL). To provide interactive simulations, a combination of the TGF and the Simulation Driver Replacement (SDRR) was used. The En Route Voice Communication Tool was used for voice communication between controller and TGF simulated pilot.

The TGF is a dynamic real-time air traffic simulation system designed to generate realistic aircraft trajectories in a simulated airspace environment. Primarily, it is used to generate interactive traffic in support of human-in-the-loop simulations. “Simulation Pilots” operate the simulated TGF aircraft and respond to air traffic control directives. TGF integrates with Simulation Driver Replacement to produce digital radar messages for aircraft. SDRR receives radar target data from TGF and transmits simulated radar data that can be used by the operational En Route systems.

Additionally, to meet the needs of the study, the IIF staff had to develop a way to feed flight plan data and aircraft track updates into the Georgia Tech ERFO algorithm so that it could look for conflicts and present recommended actions for resolutions. This was accomplished by tapping into the HNL and receiving the Common Message Set (CMS) stream from the HNL Store and Forward Application (SAFA). CMS is an FAA developed data export from the NAS flight

database. It can be used to obtain flight data information for any aircraft currently filed in the NAS. The data includes data types such as route of flight, radar position reports, facility and sector ownership, subsequent flight data amendments, etc.

Initially, Georgia Tech had proposed that the Air Traffic Controller enter all flight amendment recommendation into the operational system manually. It was quickly realized that this would not be feasible because flight amendments that change the route sometimes take a great deal of time to enter into the system. To solve this issue, a process for injecting the recommended changes into the system was needed. The SDRR, which was previously mentioned, is a specialized tool found only at the WJHTC. In addition to the functionality mentioned above, it provides a method for sending/injecting messages into the DSR Facility and Simulation Control (F&SC) network. The F&SC is another support subsystem found only at the WJHTC. From the F&SC, messages are then injected at DSR Air traffic controller positions as if they were actually typed in at the keyboard by the controller. In this way, flight plan amendments emanating from the ERFO tool were automatically entered at an air traffic control position, thus updating the NAS-filed flight data. For the purposes of maximized data collection and minimized lab utilization, the EIIF laboratory was divided in half for the study, allowing Georgia Tech to run two simulations concurrently.



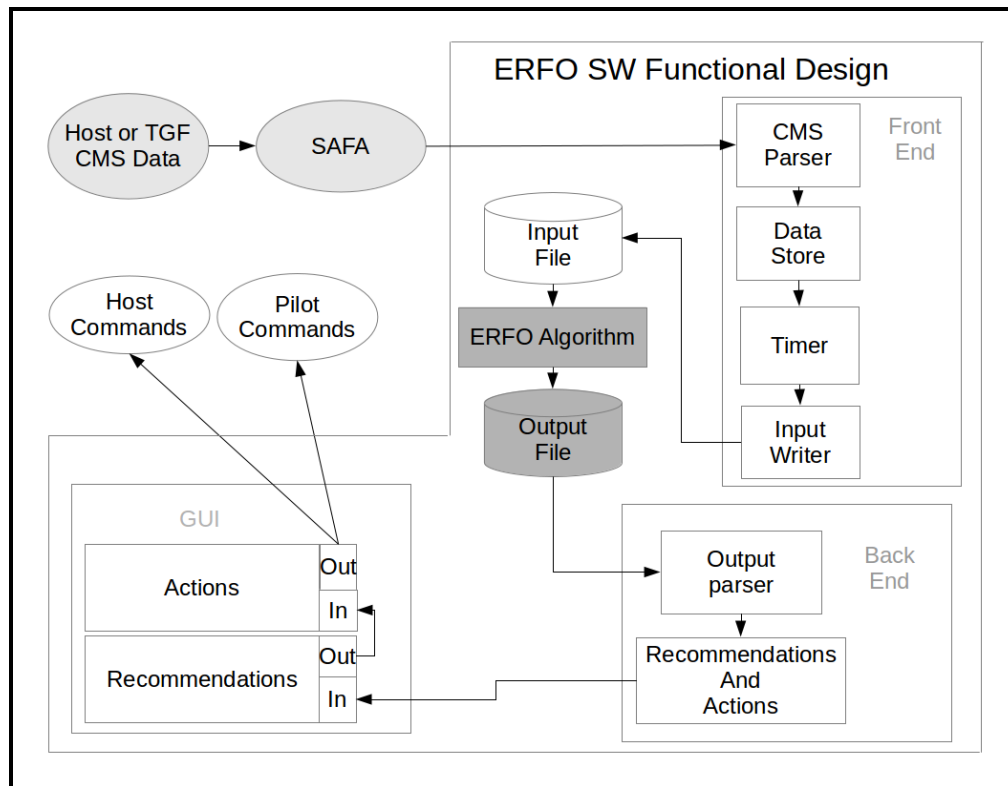
ERFO Application

The IIIF organization developed an ERFO Application that interfaced with the following:

- Georgia Tech ERFO algorithm
- FAA NAS System for receipt of flight data and entry of flight plan amendments
- Air Traffic Controller via a Graphical User Interface
- TGF radar simulation engine

The Georgia Tech developed ERFO aircraft de-confliction algorithm required as input a snapshot of all current aircraft positions (Latitude/Longitude) and velocities within the airspace. The algorithm presented this data to a Commercial off the Shelf (COTS) mathematical optimizer (IBM CPLEX). The optimizer found fuel-optimal solutions to all upcoming conflicts within the provided data set. Conflicts were defined the same way that FAA Air traffic has defined aircraft conflict in En Route airspace; within 5 miles laterally and 2000 feet vertically. The ERFO algorithm, in turn, would output fuel-optimal flight plan amendment recommendations, including a time for action. These recommendations would allow the current traffic to fall in line with the

optimizer de-confliction solutions. The required flight data set snapshot that was presented to the ERFO algorithm was captured by the EIIF developed software interface to the NAS CMS data stream as described above. This interface resided within the ERFO application. The CMS data was captured from the EIIF HNL SAFA. On an adapted periodic interval, the ERFO Application would write the latest CMS flight data to a file in the format required by the ERFO Algorithm. The application would then call the ERFO Algorithm to execute.



After the ERFO Algorithm assessed optimality using the COTS optimizer, it created an output file of recommended actions. The ERFO Application would read this output file and parse the data into recommended flight data amendments (course, speed, and/or altitude changes). Course changes were provided in the form of headings. Altitude changes were provided as a new flight level. Speed changes were provided in plus/minus increments. These recommendations were then displayed on the ERFO Air Traffic Controller's Graphical User Interface (GUI). This GUI was collocated with the tactical air traffic control radar workstation.



ERFO Application GUI

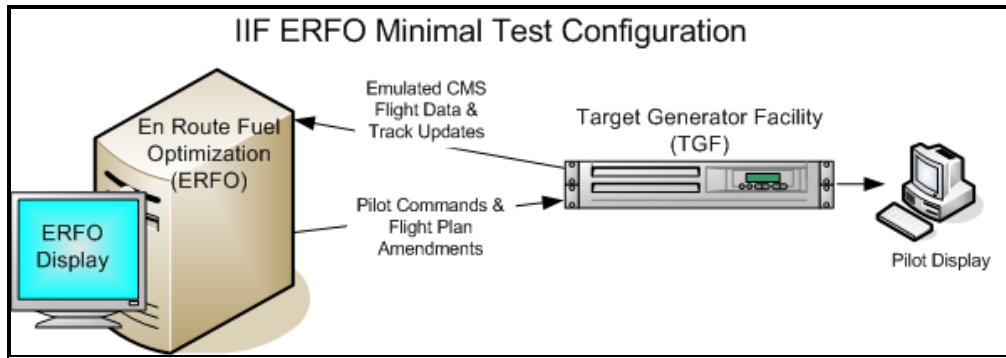
The ERFO GUI allowed the controller to accept or reject each recommendation individually. If the ERFO proposed recommendation included a route change, the GUI also allowed the controller to display the route change on the air traffic control radar display via injection of a NAS route display command (“QU” quick action key). If the controller accepted a recommendation, a flight data amendment message would be injected into the NAS system via the SDRR/F&SC systems as previously discussed. Additionally, a set of actions that were associated with that recommendation were sent to the Action list of the ERFO Application GUI. As the time for each action was reached, the controller was prompted to initiate the action. Controller actions consisted of directing a change to an aircraft via a voice communication to the pilot (TGF simulation pilot). When a voice directive is received from a controller, the simulation pilot would respond in the affirmative and then enter a command into the TGF System to change the aircraft’s radar target. Speed and altitude changes consisted of one single action. A course change recommendation consisted of 3 changes as the course deviations were all trapezoidal in shape with the aircraft resuming the original course upon completion of all three actions. The air traffic controller would then be notified of an impending action within the GUI 30 seconds prior to the required time of action entry.

As described above, the ERFO application required an air traffic controller as well as at least one simulation pilot to properly run a simulation. The EIIF organization quickly saw that this would not be feasible for day to day simulation development and system integration of the ERFO. To more efficiently execute these tasks, an “Auto Mode” was also built into the ERFO Application GUI. This function allowed for run execution without TGF Simulation Pilots. In “Auto Mode”, pilot commands for the corresponding ERFO actions were injected into TGF via a UDP/IP socket such that the simulated radar target that TGF generated would update without needing TGF Simulation pilots to enter any commands for changing the target. Another “Fully Automatic” mode was also developed such that the neither air traffic controller nor simulation pilot was required to execute a simulation. In this mode, controller and pilot actions were performed by the software on a timed basis.

Air Traffic Simulation Scenarios

There were a series of simulation scenarios that were developed for execution during the ERFO study. The IIF staff developed air traffic simulations based on data collected. The Memphis, TN ARTCC was the facility that was chosen to be represented within the configuration. Data was collected from actual traffic at the Memphis ARTCC. First, the recorded flight data was filtered down to the four Flight Levels (altitudes) which would be used in the study (FL350-380). Then those flights were given direct point to point routes through the airspace to simulate future air traffic routing. These types of routes are not what are currently being flown in the Memphis air space as was indicated in the collected data. Currently, routes are comprised of fix-based structured routes. Direct routes were required for the Georgia Tech optimizing algorithm to work properly and it was also generally agreed that they would represent a more futuristic environment; one in which this approach for aircraft separation could be implemented. IIF personnel worked with air traffic Subject Matter Experts to modify the timing of flights within the Memphis sample to create the desired number of aircraft conflicts within the air space at the flight levels of interest. Nine forty-five minute scenarios were created, with varying levels of difficulty.

To further assist with scenario development, as well as to test interim versions of ERFO application without need for controllers, pilots or any of the En Route systems, the EIIF organization enhanced the functionality of TGF. TGF was modified so that it could send emulated CMS flight data to ERFO as if it was the FAA operational NAS system. This, along with the Auto Mode function in the ERFO application for flight data recommendation command injection (described above), provided a minimal test configuration for basic testing.



HITL Study

A series of HITL studies were planned in this study, which would include air traffic controllers using the ERFO Application in conjunction with TGF simulation pilots. Additionally, a set of baseline simulations would also be executed. These baseline runs would be used for later comparison. Unfortunately, only the baseline runs were executed. Four recently retired En Route controllers participated in the baseline study. In these runs, controllers separated aircraft the way they would typically do so with the current systems. Although the final HITL simulations that included the ERFO system in the configuration were not formally executed, there were many integration activities conducted where air traffic Subject Matter Experts (SMEs) separated traffic using the ERFO application along with simulation pilots. Running in a high fidelity human in the loop environment was quite helpful during these runs. This was because most issues that surfaced were not speculative. If an issue came to light, it was quite clear that it would be a problem if the tool were to be implemented operationally. Similarly, issues could be solved with solid solutions that would remain viable upon implementation. The ERFO Graphic User Interface went through a good deal of change during this process. Recommendations and action indicators as well as timer values for actions were modified to provide the most benefit to the air traffic controller based on discussion with the air traffic SMEs participating in the activities.

Conclusion

The En Route Fuel Optimization study was a good example of a task that was able to effectively use a high fidelity air traffic control environment for the purposes of research. FAA-AEE and Georgia Tech came up with an interesting concept for a future air traffic management tool. The FAA's EIIIF organization was able to integrate the concept into the EIIIF operational NAS system, thus providing an ideal configuration for assessing the effectiveness, with certainty, of a new approach for aircraft separation that also takes into account fuel efficiency.